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Marketing Research Report No. 511

Concentrations of Methyl Bromide Lethal To Insects in Grain

Laboratory Studies of Sorption Rates and Effects of Concentrations on Rice Weevil and Confused Flour Beetle

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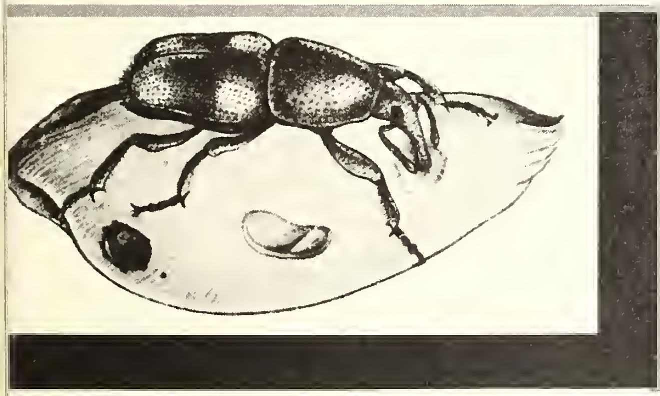

U. S. DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Market Quality Research Division

SUMMARY

Experimental fumigations with methyl bromide were conducted in grain-filled laboratory recirculators at 75° F. for various exposure periods to determine minimum effective dosage rates. Gas concentrations were measured during the fumigations by a thermal conductivity gas analyzer. Concentration-time (C.T.) products associated with complete insect mortality were determined.

Of the test insects, adult rice weevils (Sitophilus oryzae (L.)) were the most susceptible to the gas, followed by immature rice weevils and adult confused flour beetles (Tribolium confusum Duv.). Larger dosages were required when the grain moisture was higher. In general, proportionally increased exposure periods could not compensate for reduced methyl bromide concentrations. In terms of C.T. products, higher concentrations for shorter exposure periods were more efficient in killing insects than were lower concentrations for longer periods. Based on average dosages required to produce complete insect mortality, the following ranking was made: Wheat with 10 percent moisture required the least dosage, followed by wheat with 12 percent moisture; barley, 11 percent; corn, 11 percent, and oats, 12 percent (requiring equal amounts); wheat, 14 percent; grain sorghum, 11 percent; and grain sorghum, 14 percent.

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Washington, D. C. November 1961

CONCENTRATIONS OF METHYL BROMIDE LETHAL TO INSECTS IN GRAIN

Laboratory Studies of Sorption Rates and Effects of Concentrations on Rice Weevil and Confused Flour Beetle

By W. Keith Whitney and Herbert H. Walkden 1/

BACKGROUND AND PURPOSE OF WORK

Development of practical methods of measuring fumigant gas concentrations by thermal conductivity (7) 2/, and the phenomenal growth of the recirculation method of grain fumigation (9), have provided much information on penetration, distribution, and sorption of methyl bromide in stored products (2, 5, 6, 8). To give additional meaning to the gas concentration data so accumulated, laboratory tests were conducted to determine relationships between concentration, time, and mortality for representative stored-product insects in recirculators filled with different kinds of grain.

PROCEDURE AND MATERIALS

General

Experimental fumigations of different kinds of grain with methyl bromide were conducted in laboratory recirculators to determine concentrations required to kill test insects. Gas sorption by the grain was determined by thermal conductivity analyses of gas in the fumigated grain mass.

Grain

Five kinds of grain were used at various moisture contents. They were: Beecher barley, 11 percent moisture; shelled hybrid yellow dent corn, 11 percent moisture; grain sorghum (Midland variety), 11 percent and 14 percent moisture; spring oats, 12 percent moisture; and Hard Red Winter Wheat, 10 percent, 12 percent, and 14 percent moisture. Dockage in the grain was less than 1 percent. All test lots of grain were preconditioned to room temperature of 75° ± 3° F.

1/ Mr. Whitney and Mr. Walkden were formerly on the staff of the Stored-Grain Insects Laboratory, Manhattan, Kans., a station of the Stored-Product Insects Branch, Market Quality Research Division, Agricultural Marketing Service, U. S. Department of Agriculture. Mr. Whitney has resigned, and Mr. Walkden has retired.

2/ Underlined numbers in parentheses refer to items in Literature Cited, page 25.

Fumigant and Dosages

Methyl bromide (CH_3Br), which is a gas at ordinary atmospheric temperatures and pressures (b.p. 4.6° C.), is a convenient and useful fumigant for recirculation purposes. Dosages were generally started at 2.5 oz./M cu. ft. (ounces per 1,000 cubic feet, calculated on basis of total volume of recirculator) and were increased with each subsequent fumigation test in aerated wheat by a small increment (0.1 ml. per recirculator or 2.474 oz./M cu. ft.). New tests with increasing dosages were generally continued with each kind of grain at a given moisture content until complete mortality of test insects occurred after the 4-hour exposure period. The methyl bromide was measured at -15° C. in glass pipettes and was vaporized during introduction into the recirculators.

Recirculators

Three closed cylindrical test chambers (6 feet tall and 8 inches in diameter) were constructed of galvanized sheet metal. Each recirculator was fitted with a 3-inch return duct and an electrically operated blower capable of moving 50 c.f.m. (cubic feet per minute) of free air. These recirculators are illustrated in figure 1. The rate of air movement in recirculators filled with wheat (12 percent moisture) was estimated to be 0.82 c.f.m./bu. by calculations based on static pressure measurements.[3] This airflow rate provided about one complete air change per minute in a loaded recirculator. The blowers were operated during the one-half to one minute required to introduce the fumigant and for 10 minutes after introduction of the fumigant.

Test Insects

Two-week-old adults of the confused flour beetle (Tribolium confusum Duv.) and of the rice weevil (Sitophilus oryzae (L.)) and a composite of all immature stages of the rice weevil were used as test insects. The insects were reared at 80° ± 2° F. and 70 percent ± 5 percent relative humidity. Flour beetles were reared in wheat shorts.[4] Rice weevils were reared in the same kind of grain as that which was being fumigated, except for oats. The weevil population was too low in oats to provide an adequate number of immature insects in each 11-cubic centimeter test sample; therefore, rice weevils reared in wheat were used in the tests where the recirculators were filled with oats. The starting moisture content of the culture medium was 12 percent.

Thirty individuals of each species were placed in the test cages for the adult insects. Separate cages were filled with 11 cubic centimeters of the appropriate kind of grain infested with immature rice weevils. The insect test cages were probed into the grain-filled cylinders through holes located in the cylinder walls halfway between the two ends.

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[3] Measurements and calculations by Harry H. Converse, agricultural engineer, Market Quality Research Division, AMS, USDA, Manhattan, Kans.

[4] Wheat shorts are composed of small particles of endosperm, bran, and embryo. Dried brewer's yeast was added at the rate of 5 percent by weight.

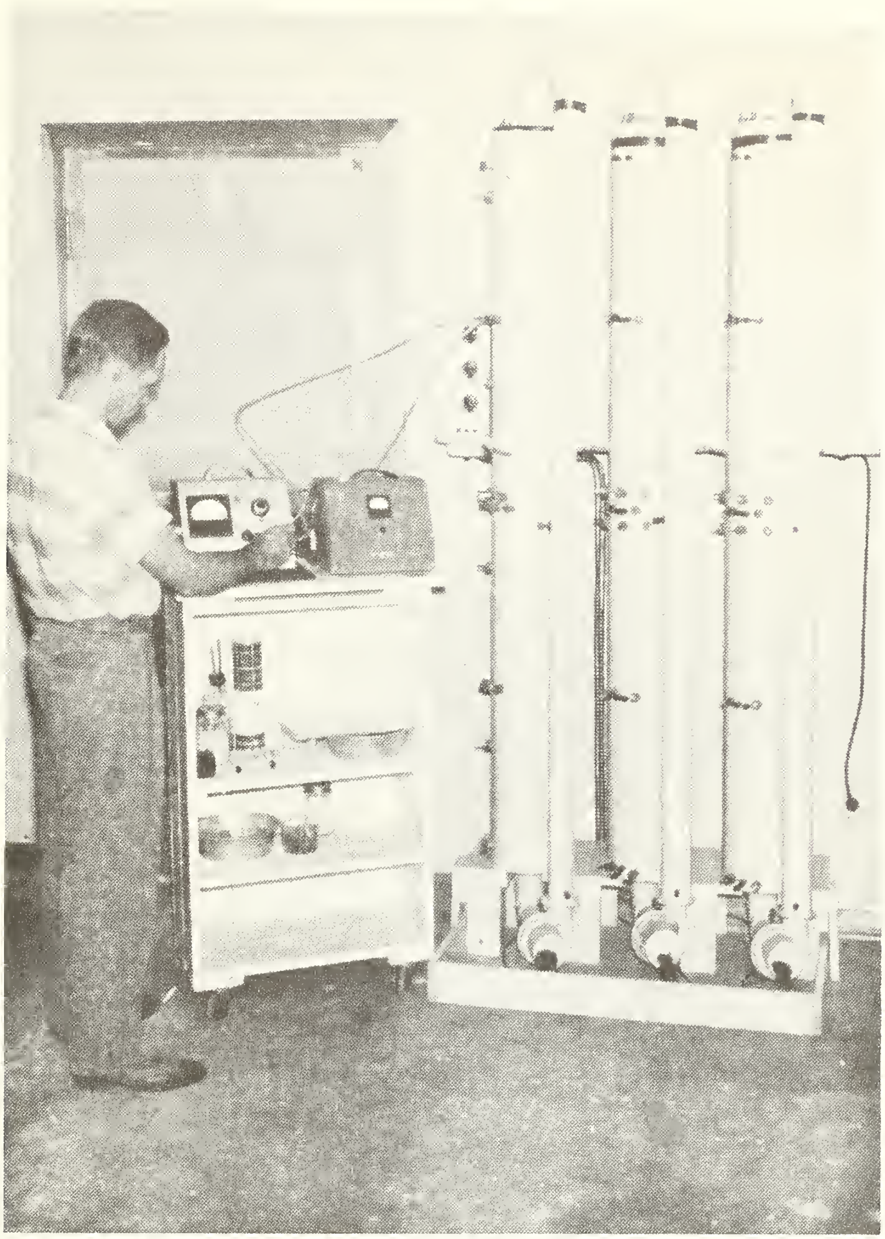

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Figure 1.--Fumigation tests were conducted in these recirculators, in which gases were forced downward through the wheat in the larger column and upward through the smaller empty return pipe. A thermal conductivity gas analyzer, being operated by a researcher, is shown attached to one of the recirculators.

Mortality counts of adult insects were taken immediately after fumigation and again 5 days later. Adults were considered dead only when no body movements could be seen. Mortality of immature rice weevils was determined by comparing the numbers of adults that emerged from fumigated samples with those that emerged from nonfumigated samples.

Exposure Periods and Temperatures

Insect samples were removed from the recirculators after exposures of 4, 8, 12, and 24 hours. Gas samples were withdrawn, analyzed, and returned to the recirculators at the end of the 10-minute recirculation period, as well as at the same intervals used for insect exposures.

The fumigations were conducted at thermostatically controlled room temperatures of 75° ± 3° F.

Gas Analyses

Samples of gas were drawn from the interstitial spaces surrounding the kernels of grain near the test insects, passed through a Gow-Mac [5] thermal conductivity gas analyzer, and returned to the recirculator. The lower limit of sensitivity of the instrument was 0.25 oz. CH_3Br/M cu. ft.

Methods of Evaluating Data

Insect mortalities were correlated with fumigant dosage rates and with methyl bromide gas concentrations observed at the selected time intervals during each fumigation. In addition, minimum concentration-time (C.T.) products associated with 100 percent mortality ($LC.T._{100}$ values) were computed for each insect species and stage in each kind of grain for each exposure period. These $LC.T._{100}$ values were derived by multiplication of the methyl bromide concentrations (oz./M cu. ft.), measured at the end of each exposure interim, by the number of hours elapsed after the previous reading (or after the start of the fumigation in the case of the 10-minute reading), and summing these products into an integrated whole. An example is cited below to illustrate the procedure. In wheat (12 percent moisture), the average minimum methyl bromide concentrations associated with 100 percent mortality of adult rice weevils 5 days after an 8-hour fumigation were 5.2 oz./M cu. ft. at 10 minutes, 3.0 oz./M cu. ft. at 4 hours, 3.0 oz./M cu. ft. at 8 hours. The time factors (interims) for these readings were 1/6, 3-5/6, and 4 hours, respectively. The component C.T. products were 0.9, 11.5, and 12.0, respectively, and the total or integrated C.T. product was 24.4 oz. hrs./M cu. ft.

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[5] The use of trade names in this report is for identification purposes only and does not constitute endorsement of the products by the U. S. Department of Agriculture.

RESULTS AND DISCUSSION

No Commodity

Six fumigations at each of three dosages were conducted in empty recirculators to obtain an estimate of the rates of gas loss without the presence of a commodity. In the following discussion, gas loss refers to that amount of the gas not recoverable. Most of the so-called loss was probably caused by sorption of the gas on the interior surface of the system. No test insects were used because previous experience had demonstrated that these dosages were in excess of that required to kill insects in empty, sealed containers (3). Gas concentration data are presented in tables 1 and 10. The data show that the rate of loss was greater at the beginning of the fumigation than during the latter part of the exposure. Percentages of gas loss were slightly greater at dosages of 12.4 and 24.7 oz./M cu. ft. than at 4.9 oz./M cu. ft.

It should not be assumed that gas loss factors due only to the recirculators would necessarily be the same in empty recirculators as in recirculators loaded with grain, because air currents, pressure differentials resulting from forced air circulation, and molecular movements would be different. The average gas loss of 14.2 percent (85.8 percent recovery) for empty recirculators during 24 hours is, however, the best figure available for use as a correction factor in estimating sorption rates by the grain. If leaks occurred, they were too small to be found with a Bernz-O-Matic halide leak detector.

Barley

Table 2 presents the results of fumigations with dosages ranging from 2.5 to 17.3 oz. CH_3Br/M cu. ft. Each figure is an average from three tests. The gas analyses are summarized in table 10. It should be noted in table 2 that the minimum dosage that produced 100 percent kill of all test insects 5 days after a 24-hour exposure (7.4 oz./M cu. ft.) was equally effective in a 12-hour exposure. Dosages of 12.4 and 17.3 oz./M cu. ft. were required for 100 percent kill by 8- and 4-hour exposures, respectively. The estimated mortality percentages for immature rice weevils are based on relative numbers of adults emerging from fumigated vs. control samples.

Corn

Results of corn fumigations are given in tables 3 and 10. In corn, as in barley, a dosage of 7.4 oz./M cu. ft. was required for complete kill of all test insects in a 24-hour exposure. Dosages of 9.9, 12.4, and 17.3 oz./M cu. ft. were required to accomplish equal results in 12-, 8-, and 4-hour exposures, respectively. Percentage mortality of immature stages was estimated, as in barley, but population levels in corn were quite low. The gas analysis data in table 10 are self-explanatory.

Grain Sorghum

Fumigations were conducted in grain sorghum of two moisture contents to observe the effects of moisture upon dosages required and sorption rates. Tables 4 and 10 contain data from tests in grain sorghum that contained 11 percent moisture. Only four dosage rates were used; however, some interesting comparisons can be made between these and results of tests in grain sorghum that contained 14 percent moisture (tables 5 and 10), in which a more extensive series of dosage rates were used.

The minimum dosages in 14 percent moisture grain sorghum that produced complete kill of test insects during four different exposure periods were: 24 hrs. 12.4 oz./M cu. ft.; 12 hrs. 17.3 oz./M cu. ft.; 8 hrs. 24.7 oz./M cu. ft.; and 4 hrs. more than 27.2 oz./M cu. ft. [6] (table 5). Somewhat lower dosages were equally effective when the moisture content was 11 percent (table 4).

Gas analyses indicated that initial sorption of methyl bromide by grain sorghum (through 4 hours' exposure) was more rapid when the moisture content was higher, but total sorption (through 24 hours' exposure) was slightly greater when the moisture content was lower (table 10). Although final interstitial gas concentrations were slightly higher in the 14 percent moisture level than in the 11 percent, the rapid initial sorption rate in the 14 percent moisture level greatly reduced the insecticidal efficiency of a given dosage.

Oats

Data from the tests in oats are shown in tables 6 and 10. As shown in table 6, the minimum exposure and dosage combinations which produced complete insect mortalities were: 24 hrs. 7.4 oz./M cu. ft.; 12 hrs. 7.4 oz./M cu. ft.; 8 hrs. 12.4 oz./M cu. ft.; and 4 hrs. 19.8 oz./M cu. ft. The weevils were reared in wheat, as explained earlier in this report.

Wheat

Fumigations were conducted in Hard Red Winter wheat at three different moisture contents to permit observation of the effects of grain moisture on fumigant performance. Tables 7, 8, and 9 present the results of tests on wheat of 10, 12, and 14 percent moisture contents, respectively. Table 10 summarizes the results of gas analyses.

The effects of wheat moisture are shown by insect mortalities and gas analyses. As observed in grain sorghum, increased moisture content generally resulted in faster gas sorption and reduced insect mortalities. The following tabulation of minimum exposure and dosage combinations (from tables 7, 8, and 9) that were required for complete insect mortality helps to illustrate the effects of moisture content:

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[6] This, the highest dosage tested, allowed survival of a few flour beetle adults.

Minimum lethal dosage for all test insects:

Exposure (Hours)	10% moisture (Oz./M cu. ft.)	12% moisture (Oz./M cu. ft.)	14% moisture (Oz./M cu. ft.)
4	14.8	17.3	19.8
8	1/12.4	9.9	12.4
12	7.4	7.4	9.9
24	4.9	7.4	7.4

1/ Mortality of 99+ percent at 9.9 oz./M cu. ft.

Concentration-Time Products

Haber's formula, c x t = C.T. (12), is a means of incorporating the important time factor into statistical expressions of fumigant concentration-mortality relationships. Many entomologists and other scientists, especially those of the British Commonwealth (1, 4, 10, and 11), make extensive use of Haber's formula.

The formula is useful, but, as Wachtel pointed out, it has shortcomings that must be considered if seriously wrong interpretations and conclusions are to be avoided. Two of these shortcomings should be mentioned.

First, each fumigant has a threshold concentration, below which insects are not killed, regardless of the length of the exposure. Obviously, when fumigations involve periods of time during which the concentration is below the threshold level, abnormally large C.T. products may be observed in connection with ineffective fumigations. To further confuse the picture, threshold values are not well known and probably vary for a given fumigant, depending upon many factors such as previous and subsequent concentrations during the course of a fumigation.

Second, C.T. products required for a specified effect under a given set of conditions vary according to the length of exposure. Within the limits of a practical fumigation, a high concentration for a short exposure is not necessarily equivalent to a low concentration for a long exposure (table 11).

Variations in the C.T. products associated with 100 percent mortality of test insects in various commodities are apparent in table 11. In general, higher concentrations over shorter exposures were more efficient than lower concentrations over longer exposures. This is in sharp contrast with the conclusion drawn by Burns Brown (1) that "for practical purposes it seems to be unimportant whether these values (methyl bromide C.T. products) are obtained by a higher concentration for a short time or a lower concentration for a correspondingly longer time, so long as the concentration for a correspondingly longer time is greater than 2 mg. per litre."

Table 1.--Average recovery of methyl bromide 1/ in 6 replications during fumigation of empty recirculators at a temperature of 75° ± 3° F.

Dosage	Recovery of methyl bromide after--														
	10 minutes			4 hours			8 hours			12 hours			24 hours		
	Range	Mean		Range	Mean		Range	Mean		Range	Mean		Range	Mean	
Oz./M cu. ft.	Oz./M cu. ft.	Oz./M cu. ft.	Pct. of dosage	Oz./M cu. ft.	Oz./M cu. ft.	Pct. of dosage	Oz./M cu. ft.	Oz./M cu. ft.	Pct. of dosage	Oz./M cu. ft.	Oz./M cu. ft.	Pct. of dosage	Oz./M cu. ft.	Oz./M cu. ft.	Pct. of dosage
4.9........	4.3- 5.3	4.9	100.0	4.5- 4.8	4.7	95.9	4.5- 4.9	4.6	93.8	4.3- 4.8	4.5	91.8	4.0- 4.5	4.4	89.8
12.4........	11.0- 12.3	11.6	93.5	10.8- 11.8	11.3	91.1	10.5- 11.8	11.0	88.7	10.5- 11.5	10.9	87.9	9.5- 11.2	10.3	83.1
24.7........	22.5- 24.1	23.6	95.5	22.0- 24.1	22.9	92.7	21.4- 23.5	22.3	90.3	20.0- 22.5	21.4	86.6	19.5- 21.5	20.9	84.6
Grand mean..			96.3			93.2			91.0			88.4			85.8

1/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.

Table 2.--Mortality of insects after methyl bromide fumigation of barley at moisture content of 11 percent, temperature of 75° ± 3° F., and test weight of 46 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
						Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min	3.0	--	--	--	--	--	--	--
4 hrs	2.0	0	1	0	0	--	52	16
8 hrs	1.7	0	1	0	0	--	42	32
12 hrs	1.7	0	5	0	0	--	40	37
24 hrs	1.0	13	24	0	0	63	29	54
4.9 oz./M cu. ft.:								
10 min	5.0	--	--	--	--	--	--	--
4 hrs	3.3	0	44	0	0	--	28	61
8 hrs	3.0	10	100	0	0	--	14	80
12 hrs	3.0	100	100	0	10	--	5	93
24 hrs	2.0	100	100	80	97	71	1	99
7.4 oz./M cu. ft.:								
10 min	8.5	--	--	--	--	--	--	--
4 hrs	5.3	0	100	0	0	--	6	90
8 hrs	5.0	82	100	0	49	--	0	100
12 hrs	4.3	100	100	20	100	--	0	100
24 hrs	3.0	100	100	100	100	63	0	100
9.9 oz./M cu. ft.:								
10 min	10.7	--	--	--	--	--	--	--
4 hrs	6.0	0	100	0	2	--	9	86
8 hrs	5.7	100	100	3	96	--	0	100
12 hrs	5.0	100	100	97	100	--	0	100
24 hrs	3.3	100	100	100	100	63	0	100
12.4 oz./M cu. ft.:								
10 min	13.3	--	--	--	--	--	--	--
4 hrs	8.0	85	100	0	66	--	0	100
8 hrs	7.0	100	100	73	100	--	0	100
12 hrs	6.3	100	100	100	100	--	0	100
24 hrs	5.3	100	100	100	100	81	0	100
14.8 oz./M cu. ft.:								
10 min	18.3	--	--	--	--	--	--	--
4 hrs	10.3	--	--	0	96	--	0	100
8 hrs	9.3	--	--	96	100	--	0	100
12 hrs	7.7	--	--	--	--	--	0	100
24 hrs	7.0	--	--	--	--	76	0	100
17.3 oz./M cu. ft.								
10 min	19.7	--	--	--	--	--	--	--
4 hrs	12.7	--	--	0	100	--	0	100
8 hrs	10.7	--	--	--	--	--	0	100
12 hrs	9.0	--	--	--	--	--	0	100
24 hrs	8.0	--	--	--	--	63	0	100

1/ Dosage calculated on basis of total volume in recirculator.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside barley kernels.
6/ Held in screen wire cages in rearing room for 24 hours.

Table 3.--Mortality of insects after methyl bromide fumigation of shelled yellow dent corn at moisture content of 11 percent, temperature of 75° ± 3° F., and test weight of 57 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
						Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min.	4.0	--	--	--	--	--	--	--
4 hrs.	2.3	0	3	0	0	--	5	0
8 hrs.	2.0	2	71	0	1	--	2	50
12 hrs.	2.0	1	78	0	0	--	2	50
24 hrs.	2.0	61	100	0	0	4	2	50
4.9 oz./M cu. ft.:								
10 min.	9.0	--	--	--	--	--	--	--
4 hrs.	5.0	3	50	0	0	--	5	83
8 hrs.	4.0	14	98	2	8	--	1	97
12 hrs.	4.0	88	100	1	9	--	1	97
24 hrs.	3.7	100	100	43	76	30	1	97
7.4 oz./M cu. ft.:								
10 min.	9.3	--	--	--	--	--	--	--
4 hrs.	5.0	3	95	3	4	--	1	93
8 hrs.	4.0	94	100	1	33	--	0	100
12 hrs.	4.0	--	--	12	79	--	0	100
24 hrs.	3.0	--	--	99	100	15	0	100
9.9 oz./M cu. ft.:								
10 min.	12.7	--	--	--	--	--	--	--
4 hrs.	6.3	14	100	0	6	--	0	100
8 hrs.	6.0	--	--	8	88	--	0	100
12 hrs.	5.0	--	--	97	100	--	0	100
24 hrs.	3.7	--	--	--	--	9	0	100
12.4 oz./M cu. ft.:								
10 min.	15.7	--	--	--	--	--	--	--
4 hrs.	8.0	36	100	0	42	--	0	100
8 hrs.	6.3	--	--	40	100	--	0	100
12 hrs.	6.3	--	--	--	--	--	0	100
24 hrs.	5.0	--	--	--	--	18	0	100
14.8 oz./M cu. ft.:								
10 min.	17.7	--	--	--	--	--	--	--
4 hrs.	9.3	77	100	0	90	--	0	100
8 hrs.	8.7	--	--	100	100	--	0	100
12 hrs.	8.0	--	--	--	--	--	0	100
24 hrs.	5.7	--	--	--	--	12	0	100
17.3 oz./M cu. ft.:								
10 min.	20.3	--	--	--	--	--	--	--
4 hrs.	10.0	--	--	0	100	--	0	100
8 hrs.	9.7	--	--	--	--	--	0	100
12 hrs.	8.7	--	--	--	--	--	0	100
24 hrs.	7.0	--	--	--	--	12	0	100

1/ Dosage calculated on basis of total volume in recirculator.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside corn kernels.
6/ Held in screen wire cages in rearing room for 24 hours.

Table 4.--Mortality of insects after methyl bromide fumigation of Midland grain sorghum at moisture content of 11 percent, temperature of 75° ± 3° F., and test weight of 58 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
						Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
4.9 oz./M cu. ft.:								
10 min.	5.0	--	--	--	--	--	--	--
4 hrs.	3.0	0	4	0	0	--	119	29
8 hrs.	1.7	0	86	0	0	--	70	58
12 hrs.	1.3	26	100	0	0	--	42	75
24 hrs.	1.0	100	100	8	12	168	22	87
9.9 oz./M cu. ft.:								
10 min.	9.7	--	--	--	--	--	--	--
4 hrs.	5.0	1	100	0	1	--	28	74
8 hrs.	4.0	96	100	1	12	--	0	100
12 hrs.	4.0	100	100	23	93	--	0	100
24 hrs.	2.0	100	100	100	99	108	0	100
14.8 oz./M cu. ft.:								
10 min.	14.0	--	--	--	--	--	--	--
4 hrs.	6.3	39	100	0	12	--	0	100
8 hrs.	6.0	--	--	1	97	--	0	100
12 hrs.	5.0	--	--	98	100	--	0	100
24 hrs.	3.0	--	--	100	100	157	0	100
19.8 oz./M cu. ft.:								
10 min.	16.7	--	--	--	--	--	--	--
4 hrs.	8.3	--	--	0	7	--	0	100
8 hrs.	6.3	--	--	30	100	--	0	100
12 hrs.	6.0	--	--	--	--	--	0	100
24 hrs.	4.7	--	--	--	--	191	0	100

1/ Dosage calculated on basis of total volume in recirculator.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside grain sorghum kernels.
6/ Held in screen wire cages in rearing room for 24 hours.

Table 5.--Mortality of insects after methyl bromide fumigation of Midland grain sorghum at moisture content of 14 percent, temperature of 75° ± 3° F., and test weight of 57 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
						Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min.	2.7	--	--	--	--	--	--	--
4 hrs.	1.7	1	2	0	2	--	111	0
8 hrs.	2.0	0	0	1	2	--	115	0
12 hrs.	2.0	0	0	0	0	--	117	0
24 hrs.	Trace	2	2	0	1	107	114	0
4.9 oz./M cu. ft.:								
10 min.	3.7	--	--	--	--	--	--	--
4 hrs.	2.0	0	0	0	1	--	98	15
8 hrs.	1.7	0	6	1	1	--	73	37
12 hrs.	1.7	0	5	0	0	--	66	43
24 hrs.	1.7	0	11	0	2	115	69	40
7.4 oz./M cu. ft.:								
10 min.	5.3	--	--	--	--	--	--	--
4 hrs.	3.3	0	53	0	0	--	65	51
8 hrs.	2.0	1	98	0	0	--	30	77
12 hrs.	2.0	48	100	0	0	--	23	83
24 hrs.	1.3	97	98	0	0	133	21	84
9.9 oz./M cu. ft.:								
10 min.	7.7	--	--	--	--	--	--	--
4 hrs.	4.0	0	60	0	1	--	68	65
8 hrs.	3.3	37	100	0	2	--	19	90
12 hrs.	3.0	99	100	0	2	--	7	96
24 hrs.	2.3	100	100	42	74	196	1	99
12.4 oz./M cu. ft.:								
10 min.	10.7	--	--	--	--	--	--	--
4 hrs.	6.0	2	100	0	3	--	14	93
8 hrs.	5.0	100	100	1	16	--	1	99
12 hrs.	4.3	100	100	8	76	--	0	100
24 hrs.	3.3	100	100	99	100	200	0	100
14.8 oz./M cu. ft.:								
10 min.	12.0	--	--	--	--	--	--	--
4 hrs.	7.7	1	100	0	0	--	5	97
8 hrs.	5.7	100	100	0	46	--	0	100
12 hrs.	5.0	100	100	44	93	--	0	100
24 hrs.	4.3	100	100	100	100	177	0	100
17.3 oz./M cu. ft.:								
10 min.	14.0	--	--	--	--	--	--	--
4 hrs.	7.3	57	100	0	8	--	8	96
8 hrs.	6.0	100	100	1	98	--	0	100
12 hrs.	5.3	--	--	75	100	--	0	100
24 hrs.	5.0	--	--	100	100	199	0	100
19.8 oz./M cu. ft.:								
10 min.	14.0	--	--	--	--	--	--	--
4 hrs.	8.3	3	100	0	1	--	3	98
8 hrs.	7.0	--	--	0	98	--	0	100
12 hrs.	6.0	--	--	78	100	--	0	100
24 hrs.	4.0	--	--	--	--	169	0	100
22.3 oz./M cu. ft.:								
10 min.	17.3	--	--	--	--	--	--	--
4 hrs.	9.3	35	100	0	3	--	1	99
8 hrs.	7.0	--	--	1	98	--	0	100
12 hrs.	6.0	--	--	--	--	--	0	100
24 hrs.	5.0	--	--	--	--	161	0	100
24.7 oz./M cu. ft.:								
10 min.	20.7	--	--	--	--	--	--	--
4 hrs.	9.7	57	100	0	52	--	0	100
8 hrs.	8.3	--	--	0	100	--	0	100
12 hrs.	7.3	--	--	--	--	--	0	100
24 hrs.	6.0	--	--	--	--	162	0	100
27.2 oz./M cu. ft.:								
10 min.	23.3	--	--	--	--	--	--	--
4 hrs.	11.0	78	100	0	97	--	0	100
8 hrs.	8.7	--	--	70	100	--	0	100
12 hrs.	8.0	--	--	--	--	--	0	100
24 hrs.	6.3	--	--	--	--	203	0	100

1/ Dosage calculated on basis of total volume in recirculators.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside grain sorghum kernels.
6/ Held in screen wire cages in rearing room for 24 hours.

Table 6.--Mortality of insects after methyl bromide fumigation of oats at moisture content of 12 percent, temperature of 75° ± 3° F., and test weight of 38 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
						Adults emerging during 6 weeks after fumigation of immature stages		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Control 6/	Fumigated	Estimated mortality
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min	2.8	--	--	--	--	--	--	--
4 hrs	2.0	0	0	0	0	--	115	11
8 hrs	1.0	0	2	0	1	--	107	17
12 hrs	1.0	0	3	0	0	--	79	39
24 hrs	.8	3	12	0	0	129	76	41
4.9 oz./M cu. ft.:								
10 min	5.3	--	--	--	--	--	--	--
4 hrs	3.3	0	81	0	0	--	69	46
8 hrs	3.0	24	99	0	1	--	44	65
12 hrs	3.0	99	100	3	4	--	42	67
24 hrs	2.0	100	100	7	7	127	26	80
7.4 oz./M cu. ft.:								
10 min	8.0	--	--	--	--	--	--	--
4 hrs	4.0	6	100	0	2	--	14	88
8 hrs	4.0	100	100	1	69	--	3	97
12 hrs	3.3	100	100	86	100	--	0	100
24 hrs	2.8	--	--	100	100	119	0	100
9.9 oz./M cu. ft.:								
10 min	10.1	--	--	--	--	--	--	--
4 hrs	5.0	12	100	0	3	--	4	.97
8 hrs	4.0	--	--	4	97	--	0	100
12 hrs	4.0	--	--	100	100	--	0	100
24 hrs	2.8	--	--	--	--	123	0	100
12.4 oz./M cu. ft.:								
10 min	13.0	--	--	--	--	--	--	--
4 hrs	7.2	5	100	0	9	--	1	99
8 hrs	6.0	--	--	50	100	--	0	100
12 hrs	4.9	--	--	--	--	--	0	100
24 hrs	3.5	--	--	--	--	124	0	100
14.8 oz./M cu. ft.:								
10 min	16.0	--	--	--	--	--	--	--
4 hrs	7.5	9	100	0	81	--	0	100
8 hrs	6.2	--	--	68	100	--	0	100
12 hrs	5.8	--	--	--	--	--	0	100
24 hrs	4.0	--	--	--	--	156	0	100
17.3 oz./M cu. ft.:								
10 min	17.8	--	--	--	--	--	--	--
4 hrs	9.4	--	--	0	82	--	0	100
8 hrs	7.5	--	--	72	100	--	0	100
12 hrs	7.5	--	--	--	--	--	0	100
24 hrs	6.0	--	--	--	--	159	0	100
19.8 oz./M cu. ft.:								
10 min	19.8	--	--	--	--	--	--	--
4 hrs	11.6	--	--	0	100	--	0	100
8 hrs	9.6	--	--	--	--	194	0	100
12 hrs	8.0	--	--	--	--	--	--	--
24 hrs	7.0	--	--	--	--	--	--	--
24.7 oz./M cu. ft.:								
10 min	25.7	--	--	--	--	--	--	--
4 hrs	14.5	--	--	0	100	--	0	100
8 hrs	11.8	--	--	--	--	194	0	100
12 hrs	10.7	--	--	--	--	--	--	--
24 hrs	8.6	--	--	--	--	--	--	--

1/ Dosage calculated on basis of total volume in recirculators.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculators.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside wheat kernels.
6/ Held in screen wire cages in rearing room for 24 hours.

Table 7.--Mortality of insects after methyl bromide fumigation of Hard Red Winter wheat at moisture content of 10 percent, temperature of 75° ± 3° F., and test weight of 62 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
						Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min.	3.0	--	--	--	--	--	--	--
4 hrs.	2.0	0	3	0	0	--	83	33
8 hrs.	2.0	0	29	0	0	--	71	43
12 hrs.	1.0	10	59	1	1	--	47	62
24 hrs.	1.0	63	75	1	7	124	33	73
4.9 oz./M cu. ft.:								
10 min.	6.3	--	--	--	--	--	--	--
4 hrs.	3.3	1	97	0	1	--	25	79
8 hrs.	3.0	44	100	0	5	--	3	98
12 hrs.	2.7	100	100	0	31	--	1	99
24 hrs.	2.0	100	100	98	100	120	0	100
7.4 oz./M cu. ft.:								
10 min.	9.3	--	--	--	--	--	--	--
4 hrs.	5.0	0	100	1	9	--	4	96
8 hrs.	4.0	100	100	6	90	--	0	100
12 hrs.	4.0	100	100	66	100	--	0	100
24 hrs.	3.0	100	100	100	100	108	0	100
9.9 oz./M cu. ft.:								
10 min.	12.7	--	--	--	--	--	--	--
4 hrs.	7.0	2	100	0	7	--	1	99
8 hrs.	6.0	100	100	10	99	--	0	100
12 hrs.	5.0	100	100	98	100	--	0	100
24 hrs.	3.7	100	100	100	100	80	0	100
12.4 oz./M cu. ft.:								
10 min.	14.7	--	--	--	--	--	--	--
4 hrs.	8.7	11	100	3	76	--	0	100
8 hrs.	7.0	--	--	43	100	--	0	100
12 hrs.	6.3	--	--	--	--	--	0	100
24 hrs.	4.7	--	--	--	--	69	0	100
14.8 oz./M cu. ft.:								
10 min.	19.3	--	--	--	--	--	--	--
4 hrs.	11.0	--	--	0	100	--	0	100
8 hrs.	9.0	--	--	--	--	--	0	100
12 hrs.	8.0	--	--	--	--	--	0	100
24 hrs.	6.3	--	--	--	--	69	0	100
17.3 oz./M cu. ft.:								
10 min.	23.7	--	--	--	--	--	--	--
4 hrs.	13.0	--	--	2	100	--	0	100
8 hrs.	10.0	--	--	--	--	--	0	100
12 hrs.	10.0	--	--	--	--	--	0	100
24 hrs.	8.0	--	--	--	--	103	0	100

1/ Dosage calculated on basis of total volume in recirculator.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside wheat kernels.
6/ Held in screen cages in rearing room for 24 hours.

Table 8.--Mortality of insects after methyl bromide fumigation of Hard Red Winter wheat at moisture content of 12 percent, temperature of 75° ± 3° F., and test weight of 59 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
						Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min.	2.8	--	--	--	--	--	--	--
4 hrs.	1.8	0	2	0	0	--	211	0
8 hrs.	1.8	0	4	0	0	--	167	11
12 hrs.	1.8	1	17	0	0	--	145	22
24 hrs.	1.0	14	33	1	1	187	137	27
4.9 oz./M cu. ft.:								
10 min.	5.2	--	--	--	--	--	--	--
4 hrs.	3.0	1	54	0	0	--	101	58
8 hrs.	3.0	21	100	0	0	--	35	85
12 hrs.	2.7	99	100	0	4	--	13	95
24 hrs.	2.2	100	100	68	77	241	3	99
7.4 oz./M cu. ft.:								
10 min.	7.8	--	--	--	--	--	--	--
4 hrs.	5.0	0	100	0	1	--	110	67
8 hrs.	4.0	91	100	0	55	--	4	99
12 hrs.	3.7	--	--	23	100	--	0	100
24 hrs.	3.0	--	--	100	100	337	0	100
9.9 oz./M cu. ft.:								
10 min.	10.7	--	--	--	--	--	--	--
4 hrs.	7.2	0	100	0	13	--	14	96
8 hrs.	5.8	--	--	0	100	--	0	100
12 hrs.	5.0	--	--	99	100	--	0	100
24 hrs.	3.3	--	--	--	--	337	0	100
12.4 oz./M cu. ft.:								
10 min.	13.2	--	--	--	--	--	--	--
4 hrs.	8.4	--	--	0	27	--	1	99
8 hrs.	7.5	--	--	6	100	--	0	100
12 hrs.	7.0	--	--	--	--	--	0	100
24 hrs.	5.0	--	--	--	--	261	0	100
14.8 oz./M cu. ft.:								
10 min.	15.2	--	--	--	--	--	--	--
4 hrs.	9.3	--	--	0	76	--	0	100
8 hrs.	8.0	--	--	--	--	--	0	100
12 hrs.	6.7	--	--	--	--	--	0	100
24 hrs.	6.0	--	--	--	--	268	0	100
17.3 oz./M cu. ft.:								
10 min.	18.0	--	--	--	--	--	--	--
4 hrs.	11.0	--	--	0	100	--	0	100
8 hrs.	9.4	--	--	--	--	--	0	100
12 hrs.	8.7	--	--	--	--	--	0	100
24 hrs.	6.8	--	--	--	--	237	0	100

1/ Dosage calculated on basis of total volume in recirculator.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside wheat kernels.
6/ Held in screen cages in rearing room for 24 hours.

Table [illegible].--Mortality of insects after methyl bromide fumigation of Hard Red Winter wheat at moisture content of 14 percent, temperature of 75° ± 3° F., and test weight of 58 lb./bu., in laboratory recirculators

Dosage and exposure 1/	Gas analysis 2/	Adult rice weevil		Adult confused flour beetle		Immature rice weevil 5/		
		Immediate mortality 3/	Delayed mortality 4/	Immediate mortality 3/	Delayed mortality 4/	Adults emerging during 6 weeks after fumigation of immature stages		Estimated mortality
						Control 6/	Fumigated	
	Oz./M cu. ft.	Percent	Percent	Percent	Percent	Number	Number	Percent
2.5 oz./M cu. ft.:								
10 min.	3.0	--	--	--	--	--	--	--
4 hrs.	2.0	0	0	0	0	--	22	35
8 hrs.	1.3	0	2	0	0	--	25	26
12 hrs.	1.0	0	5	0	0	--	25	26
24 hrs.	.5	3	10	0	0	34	20	41
4.9 oz./M cu. ft.:								
10 min.	6.0	--	--	--	--	--	--	--
4 hrs.	5.0	0	36	0	1	--	12	8
8 hrs.	3.7	25	100	0	1	--	9	31
12 hrs.	3.0	100	100	0	1	--	5	62
24 hrs.	1.2	100	100	38	56	13	2	85
7.4 oz./M cu. ft.:								
10 min.	8.3	--	--	--	--	--	--	--
4 hrs.	6.4	0	100	0	1	--	7	75
8 hrs.	5.3	100	100	0	30	--	1	96
12 hrs.	4.3	100	100	17	92	--	1	96
24 hrs.	3.5	100	100	100	100	28	0	100
9.9 oz./M cu. ft.:								
10 min.	10.3	--	--	--	--	--	--	--
4 hrs.	7.0	1	100	0	4	--	3	91
8 hrs.	5.4	--	--	1	98	--	0	100
12 hrs.	5.0	--	--	69	100	--	0	100
24 hrs.	4.0	--	--	--	--	32	0	100
12.4 oz./M cu. ft.:								
10 min.	12.5	--	--	--	--	--	--	--
4 hrs.	8.0	69	100	0	6	--	1	98
8 hrs.	6.7	--	--	92	100	--	0	100
12 hrs.	6.4	--	--	98	100	--	0	100
24 hrs.	5.0	--	--	--	--	48	0	100
14.8 oz./M cu. ft.:								
10 min.	14.5	--	--	--	--	--	--	--
4 hrs.	8.5	52	100	0	89	--	1	99
8 hrs.	7.7	--	--	13	100	--	0	100
12 hrs.	7.1	--	--	--	--	--	0	100
24 hrs.	6.0	--	--	--	--	154	0	100
17.3 oz./M cu. ft.:								
10 min.	16.5	--	--	--	--	--	--	--
4 hrs.	9.9	70	100	0	82	--	0	100
8 hrs.	8.2	--	--	16	100	--	0	100
12 hrs.	7.2	--	--	--	--	--	0	100
24 hrs.	5.3	--	--	--	--	147	0	100
19.8 oz./M cu. ft.:								
10 min.	18.5	--	--	--	--	--	--	--
4 hrs.	11.7	100	100	0	100	--	0	100
8 hrs.	9.7	--	--	100	100	--	0	100
12 hrs.	8.2	--	--	--	--	--	0	100
24 hrs.	5.7	--	--	--	--	119	0	100
22.3 oz./M cu. ft.:								
10 min.	21.4	--	--	--	--	--	--	--
4 hrs.	11.1	--	--	65	100	--	--	--
8 hrs.	9.7	--	--	--	--	--	--	--
12 hrs.	9.2	--	--	--	--	--	--	--
24 hrs.	6.4	--	--	--	--	--	--	--
24.7 oz./M cu. ft.:								
10 min.	25.2	--	--	--	--	--	--	--
4 hrs.	14.6	--	--	42	100	--	--	--
8 hrs.	11.7	--	--	--	--	--	--	--
12 hrs.	10.4	--	--	--	--	--	--	--
24 hrs.	7.6	--	--	--	--	--	--	--
27.2 oz./M cu. ft.:								
10 min.	28.8	--	--	--	--	--	--	--
4 hrs.	16.6	--	--	100	100	--	--	--
8 hrs.	15.0	--	--	--	--	--	--	--
12 hrs.	13.2	--	--	--	--	--	--	--
24 hrs.	8.5	--	--	--	--	--	--	--

1/ Dosage calculated on basis of total volume in recirculator.
2/ Analyses made with a Gow-Mac thermal conductivity gas analyzer.
3/ Within 3 hours after removal from recirculator.
4/ Five days after removal from recirculator.
5/ Composite of all stages inside wheat kernels.
6/ Held in screen cages in rearing room for 24 hours.

Table 10.--Summary of methyl bromide recovery from grain interstices at selected time intervals during fumigation at 75° ± 3° F., in laboratory recirculators

Grain and moisture content	Percentage of applied dosage 1/ 2/ recovered after exposure of--				
	10 minutes	4 hours	8 hours	12 hours	24 hours
	Percent	Percent	Percent	Percent	Percent
None (30% R.H.)	96.3	93.2	91.0	88.4	85.8
Barley:					
11 percent	66.3	40.9	36.5	32.9	24.4
Corn:					
11 percent	68.9	37.1	32.0	30.6	26.8
Grain sorghum:					
11 percent	47.4	24.6	18.4	16.4	10.6
14 percent	40.9	21.8	19.1	17.6	12.5
Oats:					
12 percent	62.0	34.7	27.8	25.6	19.5
Wheat:					
10 percent	63.5	36.1	30.8	25.9	20.4
12 percent	53.2	33.4	29.6	27.2	20.0
14 percent	52.4	34.0	27.3	23.8	17.5

1/ Percentage recovered calculated on basis of dosage on free airspace only. Free airspace was estimated to be 50 percent of total recirculator volume for corn, grain sorghum, or wheat, and 58.7 percent for barley or oats.

2/ Each figure is an average of several tests at different dosages.

Table 11.--Minimum methyl bromide concentration-time (C.T.) 1/ products associated with 100 percent kill of test insects in grain-filled recirculators at 75° F.

Insect, grain, and moisture content	C.T. products associated with 100% kill (LC. T. $_{100}$)			
	4-hour exposure	8-hour exposure	12-hour exposure	24-hour exposure
	Oz. hrs./M cu. ft.	Oz. hrs./M cu. ft.	Oz. hrs./M cu. ft.	Oz. hrs./M cu. ft.
Rice weevil (adults):				
Barley:				
11 percent	22	25	37	61
Corn:				
11 percent	26	37	53	49
Grain sorghum:				
11 percent	21	37	24	36
14 percent	25	30	52	69
Oats:				
12 percent	17	33	38	62
Wheat:				
10 percent	21	26	37	61
12 percent	20	24	35	62
14 percent	26	35	47	61
Rice weevil (immature stages):				
Barley:				
11 percent	33	42	59	95
Corn:				
11 percent	26	37	53	89
Grain sorghum:				
11 percent	26	37	53	77
14 percent	41	54	65	102
Oats:				
12 percent	31	37	46	79
Wheat:				
10 percent	36	37	53	61
12 percent	38	53	73	87
14 percent	41	30	70	106
Confused flour beetle (adults):				
Barley:				
11 percent	52	61	59	95
Corn:				
11 percent	49	58	70	89
Grain sorghum:				
11 percent	--	60	70	106
14 percent	>46 (97% kill)	74	76	102
Oats:				
12 percent	48	54	46	79
Wheat:				
10 percent	45	64	53	61
12 percent	45	53	51	87
14 percent	48	60	70	106

1/ Integrated summation of concentration readings in ounces per 1,000 cubic feet multiplied by time intervals in hours.

Comparison of Grains

The relative efficiency of methyl bromide in fumigating the five kinds of grain used in these tests can be shown by examination of insect mortalities, of gas recoveries which reflect sorption rates, and of effective C.T. products.

Based on average dosages required to produce 100 percent mortality of all test insects, the following ranking was made: Wheat with 10 percent moisture requires the least dosage; progressively more is required by wheat with 12 percent moisture; barley, 11 percent moisture; corn, 11 percent moisture, and oats 12 percent moisture (equal dosages); wheat, 14 percent moisture; grain sorghum, 11 percent moisture; and grain sorghum, 14 percent moisture.

Recoveries of methyl bromide gas from seed interstices (table 10) indicate the following ranking, from most to least: Barley, 11 percent moisture; corn, 11 percent moisture; wheat, 10 percent moisture; oats, 12 percent moisture; wheat, 12 percent moisture; wheat, 14 percent moisture; grain sorghum, 11 percent moisture; and grain sorghum, 14 percent moisture.

Ranking according to average C.T. products associated with complete insect mortalities was as follows: Wheat, 10 percent moisture, had the lowest levels, followed progressively by oats, 12 percent moisture; grain sorghum, 11 percent moisture; wheat, 12 percent moisture; corn, 11 percent moisture; barley, 11 per percent moisture; wheat, 14 percent moisture; and grain sorghum, 14 percent moisture.

Outstanding among these observations were the adverse effects of higher moisture contents upon dosages and C.T. products required and the fact that grain sorghum required considerably larger dosages than other grains at comparable moisture contents.

Comparison of Test Insects and of Exposure Periods

Regardless of the kind of grain, moisture content, or length of exposure, adult rice weevils were most susceptible and adult confused flour beetles were least susceptible to methyl bromide (see following tabulations, figures 2-4, and tables 2-9 and 11). Differences were generally more pronounced in the shorter exposures than in the longer ones. The latent effects of methyl bromide were important, as evidenced by the large increases in insect mortality during the 5 days between the immediate and delayed counts.

As previously mentioned, higher concentrations over shorter exposure periods were generally found to be more efficient than lower concentrations over longer exposure periods. This phenomenon is illustrated in two ways.

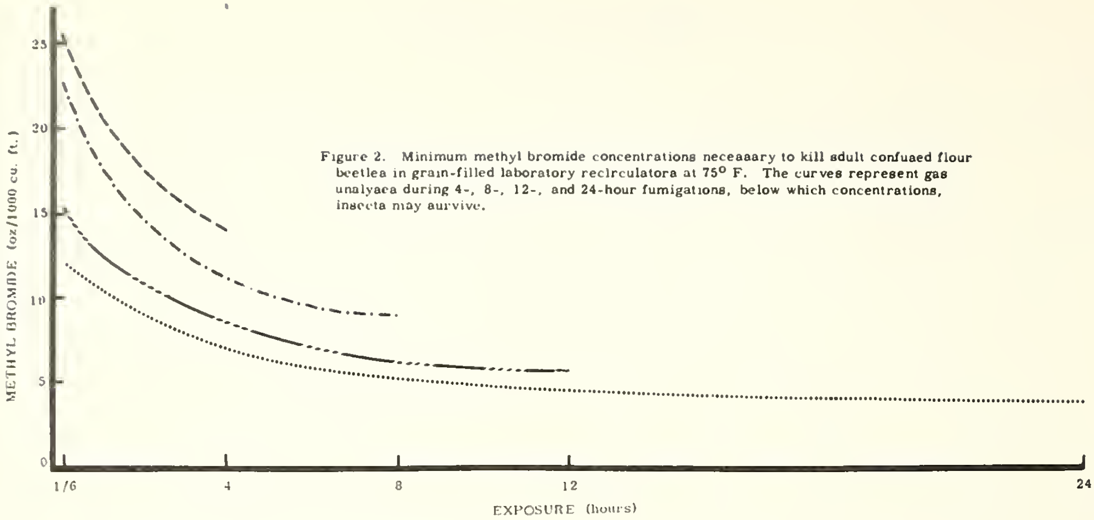

Figure 2. Minimum methyl bromide concentrations necessary to kill adult confused flour beetles in grain-filled laboratory recirculators at 75° F. The curves represent gas analyses during 4-, 8-, 12-, and 24-hour fumigations, below which concentrations, insects may survive.

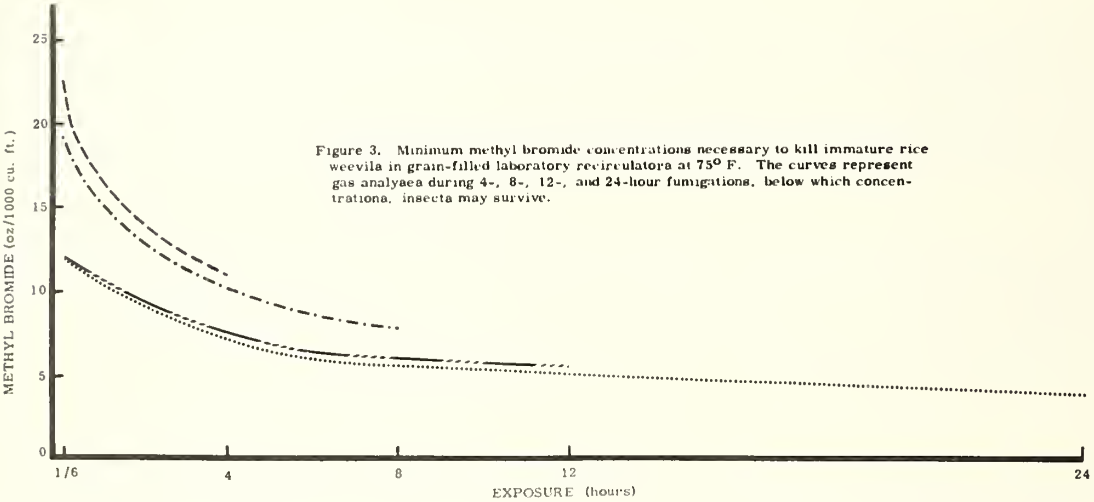

Figure 3. Minimum methyl bromide concentrations necessary to kill immature rice weevils in grain-filled laboratory recirculators at 75° F. The curves represent gas analyses during 4-, 8-, 12-, and 24-hour fumigations, below which concentrations, insects may survive.

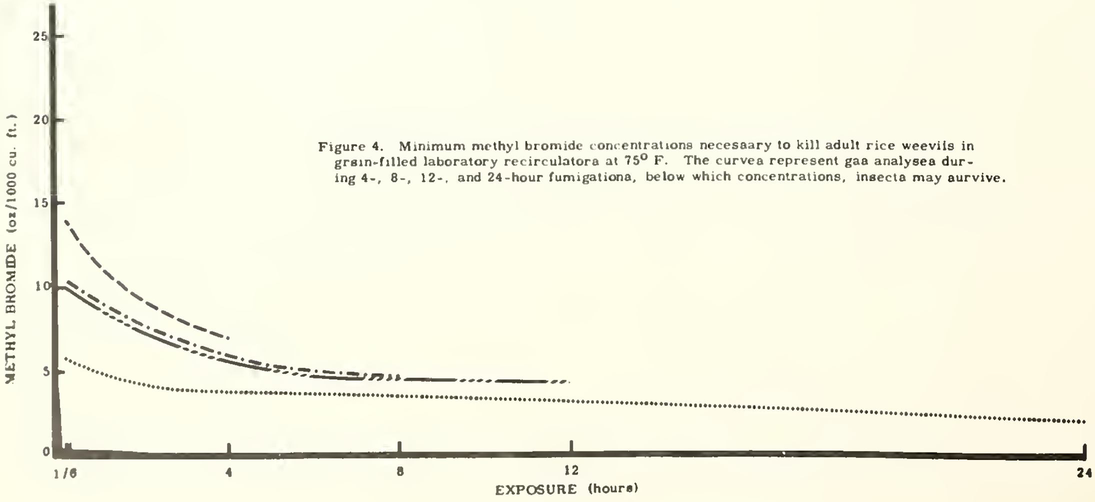

Figure 4. Minimum methyl bromide concentrations necessary to kill adult rice weevils in grain-filled laboratory recirculators at 75° F. The curves represent gas analyses during 4-, 8-, 12-, and 24-hour fumigations, below which concentrations, insects may survive.

First, the average applied dosages required to kill all of the test insects in the various kinds of grain were as follows:

Exposure (Hours)	Adult rice weevils (Oz./M cu. ft.)	Immature rice weevils (Oz./M cu. ft.)	Adult confused flour beetles (Oz./M cu. ft.)
4	8.7	14.5	19.1
8	6.8	9.6	14.6
12	5.5	8.7	10.2
24	5.2	8.0	8.3

It is obvious that for each increase in exposure, the decrease in dosage was not proportional.

Second, the average C.T. products associated with complete mortality of all test insects in the various kinds of grain were as follows:

Exposure (Hours)	Adult rice weevils (Oz./M cu. ft.)	Immature rice weevils (Oz./M cu. ft.)	Adult confused flour beetles (Oz./M cu. ft.)
4	22	34	48
8	31	41	61
12	40	59	62
24	58	87	91

Again, it is obvious that effective interstitial gas concentrations were not decreased in proportion to the increased exposure periods. If this had been the case, the concentration-time (C.T.) products would have been constant, regardless of the exposure period.

Figures 2-4, which illustrate the minimum methyl bromide concentrations necessary to kill all test insects, also show that increased exposures did not allow corresponding decreases in gas concentrations.

Relationship Between These Findings and Others

Monro et al. (11) and Burns Brown (1) have estimated minimum C.T. products for a 99.9 percent kill of several insects. Monro mentioned a 20-hour exposure period, but Burns Brown did not state what exposure periods were used in obtaining his data. Furthermore, neither paper states whether the C.T. products were obtained in fumatoria with a load, and therefore a changing gas concentration, or in empty fumatoria, where the gas concentration would remain more nearly constant throughout the exposure.

Although ample allowance is needed for the unknowns mentioned, a few comparisons can be made. Table 12 shows estimated minimum C. T. products for rice weevils and confused flour beetles at 25° C. Some conspicuous deviations are apparent. However, these could be due to differences in test conditions as mentioned previously.

Table 12.--Estimated minimum concentration-time products for kill of rice weevils and confused flour beetles by fumigation with methyl bromide at a temperature of 25° C.

Authority	Adult rice weevils	Immature rice weevils	Adult confused flour beetles	Mortality
	Oz. hr./M cu. ft.	Oz. hr./M cu. ft.	Oz. hr./M cu. ft.	Percent
Burns Brown....	30	85	60	99.9
Monro et al....	--	--	70	99.9
Whitney				
(Minimum)....	17	26	45	100
(Average)....	38	55	65	100
(Maximum)....	69	106	106	100

Minimum Effective Concentrations

In view of the present data, recommendations as to minimum effective C.T. products should be based upon the insects involved, the kind and condition of the grain to be fumigated, and the length of the exposure period. Table 11 shows several observed effective C.T. values for rice weevils and confused flour beetles at 75° F.

Figures 2, 3, and 4 show minimum gas concentration curves which produced complete mortality of adult confused flour beetles, immature rice weevils, and adult rice weevils, respectively, after fumigation with methyl bromide at 75° F. Each graph contains four curves, one for each exposure period studied. Data used in constructing the curves were obtained by adding a factor of 10 percent to the observed minimum gas concentration readings associated with 100 percent mortality for each group of test insects in each kind and moisture content of grain. These adjusted gas concentration readings were then plotted on ordinary graph paper and a smooth curve was drawn through the highest points. Complete insect mortality should be expected after a 4-, 8-, 12-, or 24-hour fumigation in which gas concentrations equal or exceed those indicated by the appropriate curve.

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